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Hydroelectric Generation

Welding Procedures

Author and Presenter

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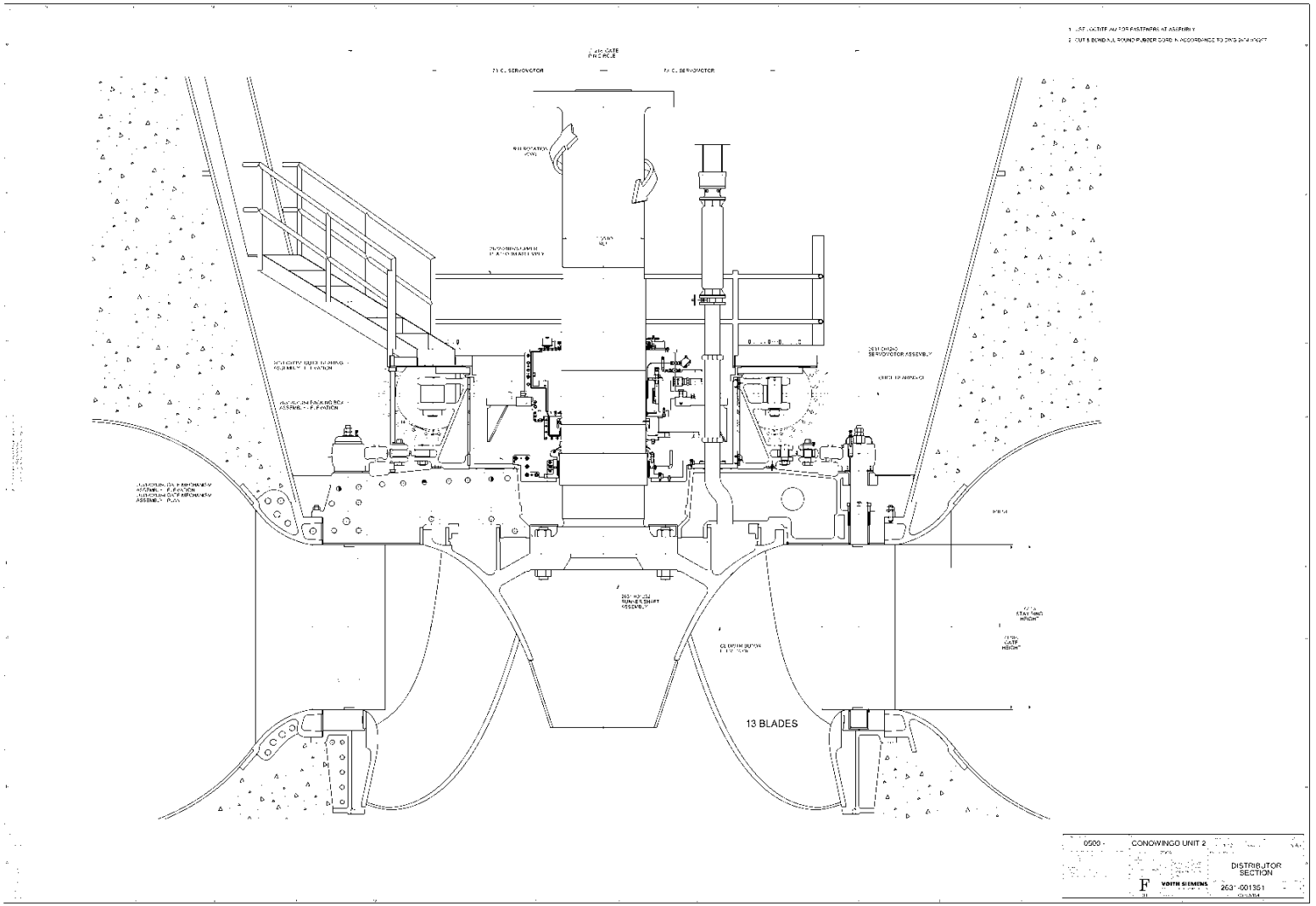
Cross Section of Turbine Assy.



Purpose of this presentation

- Identify the what and why of welding procedures
- Provide a general understanding of their purpose
- To describe why they are imperative in Hydro
- Convey an understanding of the complexity of complying with industry standards

Does your project have/use/write procedures?

- How to operate your equipment; start up/shutdown?
- Perform daily/weekly/monthly/Quarterly/Annual maintenance functions using procedures?
- Maintain logs of performance?
- Pretty sure you do
- So.....
- Do you have and use welding procedures?
- Are your welders qualified and their records current?

What is a Welding Procedure?

- Welding procedures provide information to welders and interested parties; how to make / expected performance
  - Welding Specification Procedures (WPS's) convey the parameters and techniques for a particular weld – 'the recipe'; includes essential and non essential variables
  - WPS's are derived from PQR's
  - Procedure Qualification Records (PQR's) reports 'the results' of a recipe; the mechanical performance of a given weld, includes various destructive and non-destructive tests
  - Welder Performance Qualification Record (WPQR) documents welder skills

Why a Welding Procedure?

- Pop Quiz
  - A. Procedures are a means for Welding Engineers to show everyone they are smart
  - B. Procedures are only for Welders who don’t know what they are doing
  - C. Procedures are to be written, filed, and never see the light of day again
  - D. Procedures describe essential and non-essential variables of a process in order to achieve a predictable and repeatable outcome
  - E. Procedures are not needed; ‘Joe’ is a really good welder

Why a Welding Procedure?

- Pop Quiz Audience Answers?
- Yes, as everyone knows, the correct answer is .....
- E!
  - Procedures are not needed; ‘Joe’ is a really good welder!!
- But seriously,
  - Procedures describe essential and non-essential variables of a process to achieve a predictable and repeatable outcome

Why a Welding Procedure?

- Why is a predictable and repeatable outcome important?
  - Hydroelectric machines are large rotating masses
  - They contain high pressure water
  - Failure can have catastrophic consequences

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2009 Sayano–Shushenskaya power station accident

The **2009 Sayano–Shushenskaya hydroelectric power station accident** occurred at 00:13 GMT on 17 August 2009, (08:13 AM local time) when Turbine 2 of the Sayano-Shushenskaya hydroelectric power station in Khakassia, Russia, broke apart violently. The turbine hall and engine (generator) room were flooded, the ceiling of the turbine hall collapsed, 9 of 10 turbines were damaged or destroyed, **and 75 people were killed**. The entire plant output, totaling 6,400 MW and a significant portion of the supply to the local electric grid, was lost, leading to widespread power failures. An official report on the accident was issued on 4 October 2009.
Source: Wikipedia

Cause: Damaged turbine welding repairs left the runner imbalanced. U2 Vibrations were 4 times the maximum limit at failure. High operating stresses imposed by a newly installed control system may have caused the runner to shed sections and further imbalance; uneven flow pulses back pressured the penstocks creating a water hammer and the head cover bolts failed (6 nuts were missing) and the rotor and runner climbed out of the pit.

Procedural Failure?

- Not suggesting that a lack of welding procedure was the root cause; but, original manufacture and subsequent repair welding were clearly implicated and part of the failure mechanism
- If I were the Russian welding engineer I would want to have the best PQR's, WPS's and WPQR's ever produced to cover my rear!

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P.O Box 712, York, Pa. 17405

ASME - Welding Procedure Specification (WPS)

WeldOffice WPS

WPS record number	8101-B-S Revision 8	Qualified to	ASME IX
Date	07/23/79(orig issue)	Company name	Voith Hydro

PREHEAT TABLE

Applicable standard	
VSY Practices	60F Min., except 100F Min. for A668 Cl. D. Preheat higher than indicated is mandatory when specified on process routing.
WELD JOINTS	Full penetration weld joints shall be backgouged to sound metal by air carbon arc gouging, machining or grinding prior to welding the second side.
VSY Practices	Welders who perform work to this procedure shall be qualified to Voith Siemens Hydro performance qualification Test No. 8101-A-T.

POST WELD HEAT TREATMENT (QW-407)

Temperature	(°F)	1100-1200	Time	(hrs)	6.25 Max.	Type	Stress relief
Heating rate	(°F/hr)	Per ASME VIII, Div. 1	Method		Furnace		
Cooling rate	(°F/hr)	Per ASME VIII, Div. 1	Method		Furnace		
Notes							
		Preheat maintenance after completion of welding prior to PWHT (QW-406.2)				Temperature	(°F) None

TECHNIQUE (QW-410)

Peening	Not used Unless Specified in the Routing
Surface preparation	Thermal Cut and/or Ground
Initial/Interpass cleaning	Slagging Chisel / Hammer, Grind and/or Wire Brush
Back gouging method	Air carbon arc

NOTES

Electrode Dia. in. (mm)	Current Voltage	Flat/Horizontal	Vertical	Overhead
3/32 (2.4)	21-24	80-110	80-95	80-100
1/8 (3.2)	21-24	110-160	90-140	100-120
5/32 (4.0)	22-25	135-220	130-170	135-190
3/16 (4.8)	23-26	210-300	180-250	

Welding Engineer

Name	Signature
David R. Johnson	David R. Johnson
Date	
01/27/2003	

Uncontrolled when printed.

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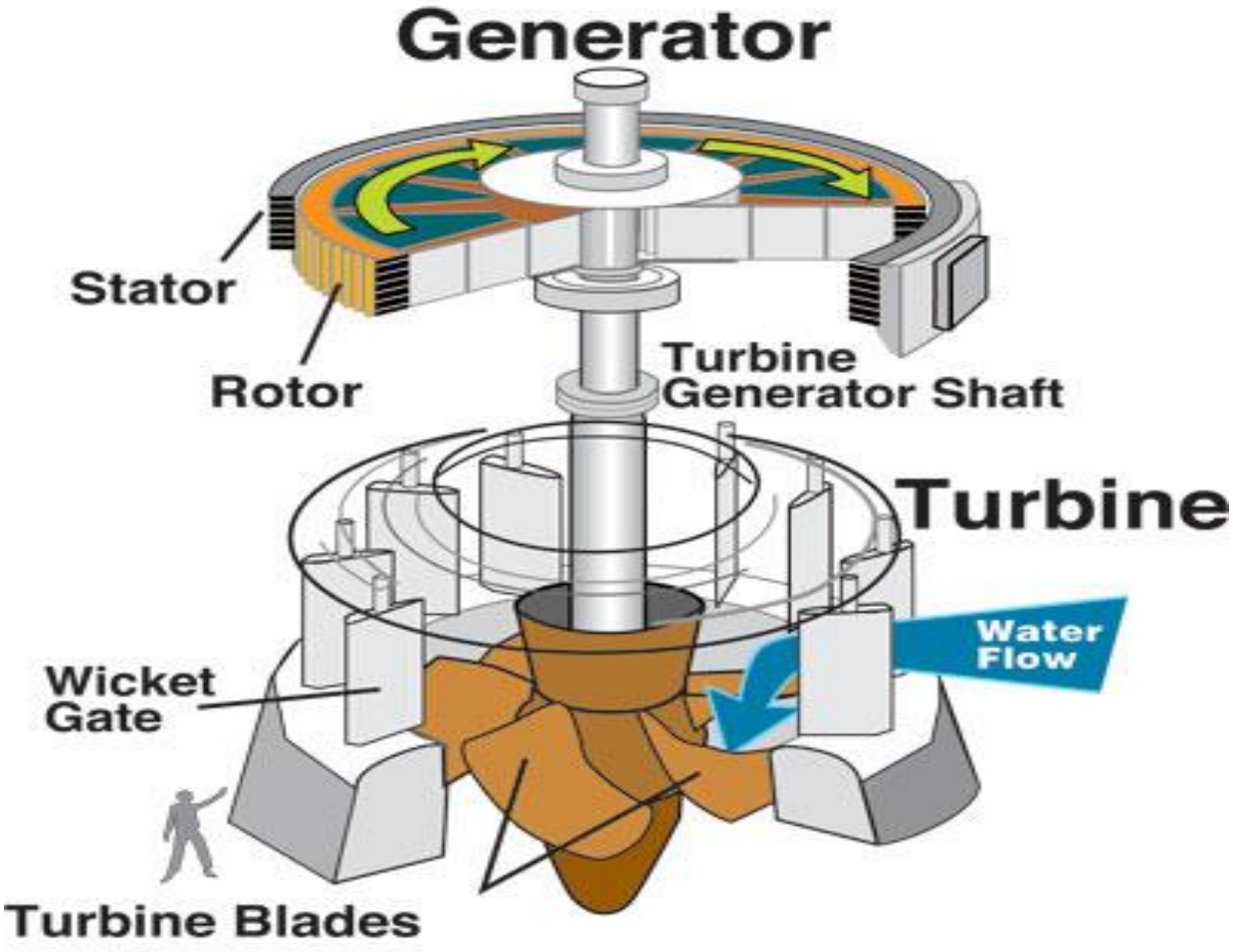
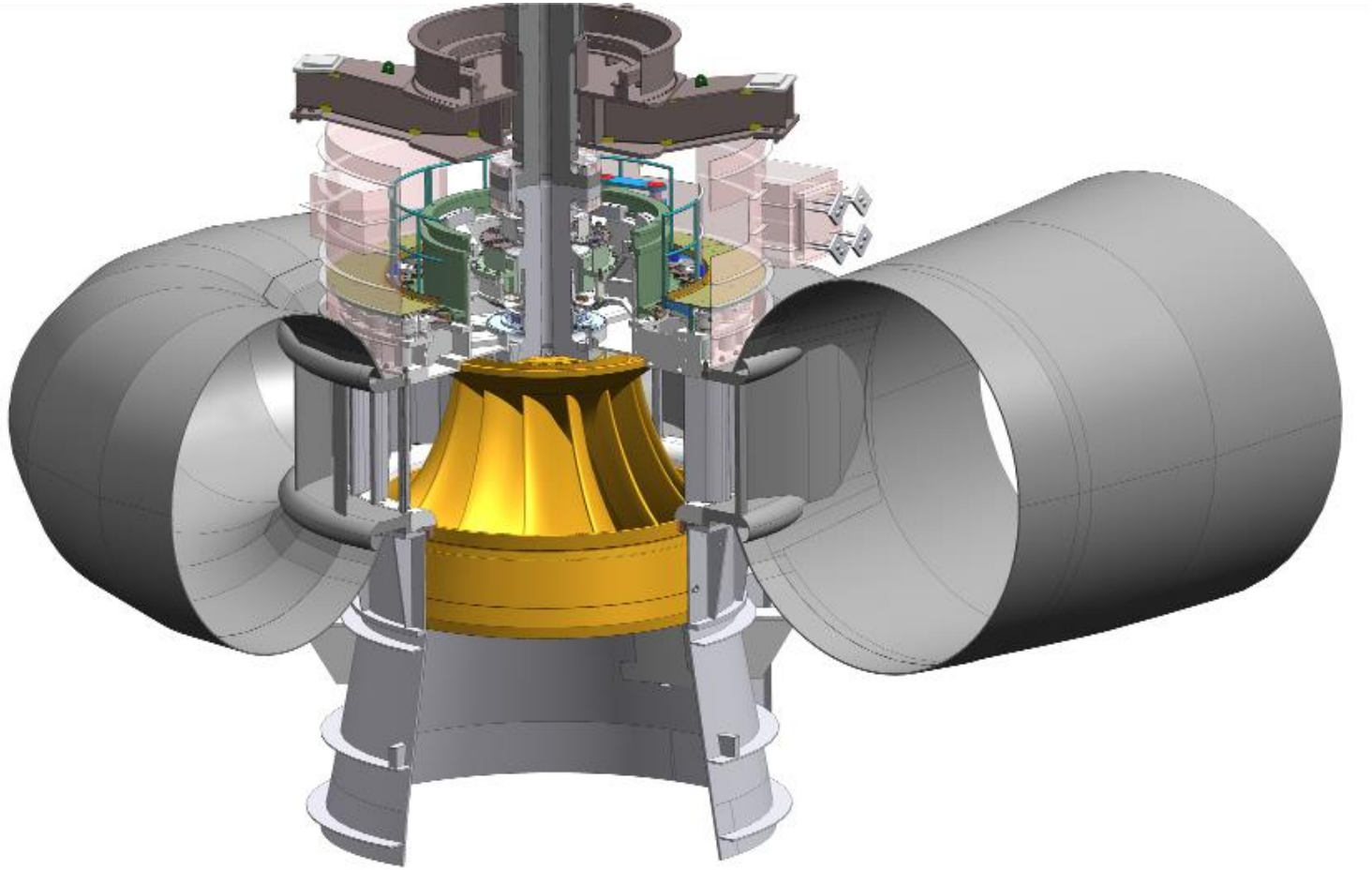
Where in the machine do we weld or braze?

Everywhere: original manufacture, rehab and repairs



Where in the machine do we weld or braze?

Everywhere in original manufacture and subsequent repairs



What's so bad about **NOT** having qualified procedures?

- If the Russian disaster was not sufficient lets look at the results of a few domestic concerns

Getting it wrong

Liner ripped from the wall, note the anchor

Another reason to get it right

- This utility had a failure of the spill gate lifting mechanism
- Dam safety was impacted
- Immediately got the attention of FERC
- 3rd party engineering consultants brought in to oversee repairs
- Design solution and welding documentation heavily scrutinized
- Strict QA procedures throughout repairs
- 10 gates repaired
- Good results. Utility is looking forward to another 100 years of safe operation

Standards and Codes

- Standards and Codes – AWS D1.1 and ASME VIII and IX
- AWS D1.1Structural Welding Code; 132 of 500 pages, Clauses 3 (prequalification) and 4 (qualification)
- ASME IX Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators; all 340 pages address qualification
- ASME VIII Rules for Construction of Pressure Vessels (700 pages); welding is an integral process
- Standards and Codes specify requirements to produce WPS's
- All WPS's and derived from and supported by a PQR

ASME IX Brief Introduction

The following is a brief introduction to the 2007 Edition of Section IX and cannot be considered as a substitute for the actual review of appropriate sections of the document. However, this introduction is intended to give the reader a better understanding of the purpose and organization of Section IX. **Section IX of the ASME Boiler and Pressure Vessel Code relates to the qualification of welders, welding operators, brazers, and brazing operators, and the procedures employed in welding or brazing in accordance with the ASME Boiler and Pressure Vessel Code and the ASME B31 Code for Pressure Piping**. As such, this is an active document subject to constant review, interpretation, and improvement to recognize new developments and research data. Section IX is a document referenced for qualification by various construction codes such as Section I, III, IV, VIII, etc. These particular construction codes apply to specific types of fabrication and may impose additional welding requirements or exemptions to Section IX qualifications. Qualification in accordance with Section IX is not a guarantee that procedures and performance qualifications will be acceptable to a particular construction code. **Section IX establishes the basic criteria for welding and brazing which are observed in the preparation of welding and brazing requirements that affect procedure and performance.** It is important that the user of the 2007 Edition of Section IX understand the basic criteria in reviewing the requirements which have been established. Section IX does not contain rules to cover all welding and brazing conditions affecting production weld or braze properties under all circumstances. Where such welding or brazing conditions are determined by the Manufacturer to affect weld or braze properties, the Manufacturer shall address those welding or brazing conditions to ensure that the required properties are achieved in the production weldment or brazement. **The purpose of the Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR) is to determine that the weldment proposed for construction is capable of having the required properties for its intended application.** It is presupposed that the welder or welding operator performing the welding procedure qualification test is a skilled workman.

ASME IX Brief Introduction

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This also applies to the Brazing Procedure Specifications (BPS) and the brazer and brazing operator qualifications. The procedure qualification test is to establish the properties of the weldment or brazement xxiii and not the skill of the personnel performing the welding or brazing. In addition, special consideration is given when notch toughness is required by other Sections of the Code. The notch-toughness variables do not apply unless referenced by the construction codes. In Welder or Brazer /Brazing Operator Performance Qualification, the basic criterion is to determine the ability to deposit sound weld metal, or to make a sound braze. In Welding Operator Performance Qualification, the basic criterion is to determine the mechanical ability of the welding operator to operate the equipment. In developing the present Section IX, each welding process and brazing process that was included was reviewed with regard to those items (called variables) which have an effect upon the welding or brazing operations as applied to procedure or performance criteria. The user of Section IX should be aware of how Section IX is organized. It is divided into two parts: welding and brazing. Each part is then divided into articles. These articles deal with the following:

(a) general requirements (Article I Welding and Article XI Brazing) *(b)* procedure qualifications (Article II Welding and Article XII Brazing) *(c)* performance qualifications (Article III Welding and Article XIII Brazing) *(d)* data (Article IV Welding and Article XIV Brazing) *(e)* standard welding procedures (Article V Welding) **These articles contain general references and guides that apply to procedure and performance qualifications such as positions, type and purpose of various mechanical tests, acceptance criteria, and the applicability of Section IX**, which was in the Preamble of the 1980 Section IX (the Preamble has been deleted). The general requirement articles reference the data articles for specifics of the testing equipment and removal of the mechanical test specimens.

ASME IX Brief Introduction

QW-423 Alternate Base Materials for Welder Qualification

QW-423.1 Base metal used for welder qualification may be substituted for the metal specified in the WPS in accordance with the following table. When a base metal shown in the left column is used for welder qualification, the welder is qualified to weld all combinations of base metals shown in the right column, including unassigned metals of similar chemical composition to these metals. Base Metals for Welder Qualified Production Qualification Base Metals

P- or S-No. 1 through P- or P- or S-No. 1 through P- or S- No. 11, P- or S-No. 34, S- No. 11, P- or S-No. 34, and P- or S-No. 41 and P- or S-No. 41 through P- or S-No. 49 P- or S-No. 49 P- or S-No. 21 through P- or P- or S-No. 21 through P- or S- No. 26 S- No. 26 P- or S-No. 51 through P- or P- or S-No. 51 through P- or S-No. 53 or P- or S-No. 61 S- No. 53 and P- or S-No. through P- or S-No. 62 61 through P- or S-No. 62 **QW-423.2** Metals used for welder qualification conforming to national or international standards or specifications may be considered as having the same P- or S-Number as an assigned metal provided it meets the mechanical and chemical requirements of the assigned metal. The base metal specification and corresponding P- or S-Number shall be recorded on the qualification record.

QW-424 Base Metals Used for Procedure Qualification

QW-424.1 Base metals are assigned P- or S-Numbers in table QW/QB-422; metals that do not appear in table QW/QB-422 are considered to be unassigned metals except as otherwise defined in QW-420.1 for base metals having the same UNS numbers. Unassigned metals shall be identified in the WPS and on the PQR by specification, type and grade, or by chemical analysis and mechanical properties. The minimum tensile strength shall be defined by the organization that specified the unassigned metal if the tensile strength of that metal is not defined by the material specification.

128 Base Metal(s) Used for Procedure Qualification Coupon Base Metals Qualified One metal from a P-Number to Any metals assigned that P- or

any metal from the same S-Number P-Number One metal from a P-Number to Any metal assigned the first any metal from any other P- or S-Number to any P- Number metal assigned the second P or S-Number One metal from P-No. 3 to Any P- or S-No. 3 metal to any metal from P-No. 3 any metal assigned P- or S-No. 3 or 1 One metal from P-No. 4 to Any P- or S-No. 4 metal to any metal from P-No. 4 any metal assigned P- or S-No. 4, 3, or 1 One metal from P-No. 5A to Any P- or S-No. 5A metal to any metal from P-No. 5A any metal assigned P- or S-No. 5A, 4, 3, or 1 One metal from P-No. 5A to a Any P- or S-No. 5A metal to metal from P-No. 4, or any metal assigned to P- or P-No. 3, or P-No. 1 S-No. 4, 3, or 1 One metal from P-No. 4 to a Any P- or S-No. 4 metal to metal from P-No. 3 or any metal assigned to P- or P-No. 1 S-No. 3 or 1 Any unassigned metal to the unassigned metal to itself.

Standards and Codes

- All welders should be qualified to weld to a Standard/Code, process, base metal group and position
- Might use pre-qualified or require a developed procedure
- May also need supplementary procedures for:-
  - Distortion control, pre-heat and post heat, interim stress relief, NDE inspections

Conclusion

- Welding is a critical process in the original production, repair and rehabilitation in Hydro power generation machines
- High Pressure vessels, massive rotating machines
- Do not underestimate the role of welding in safe operations
- No one should weld on equipment without proper knowledge, qualifications and procedures
- If you don’t have the experts on staff, hire competent contractors or consultants
- Always maintain good records to know what was done, how and by who

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Engineered Reliability

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Welding for Hydroelectric Generation

Processes

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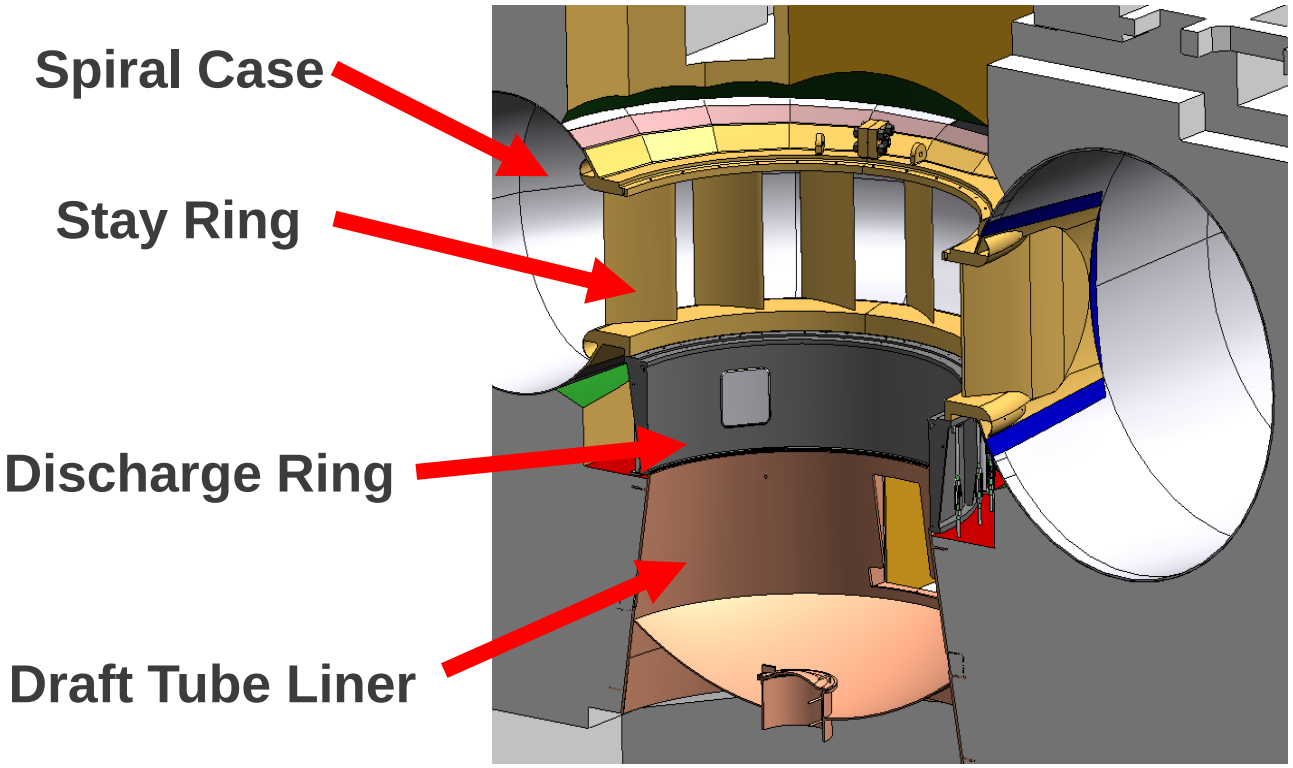
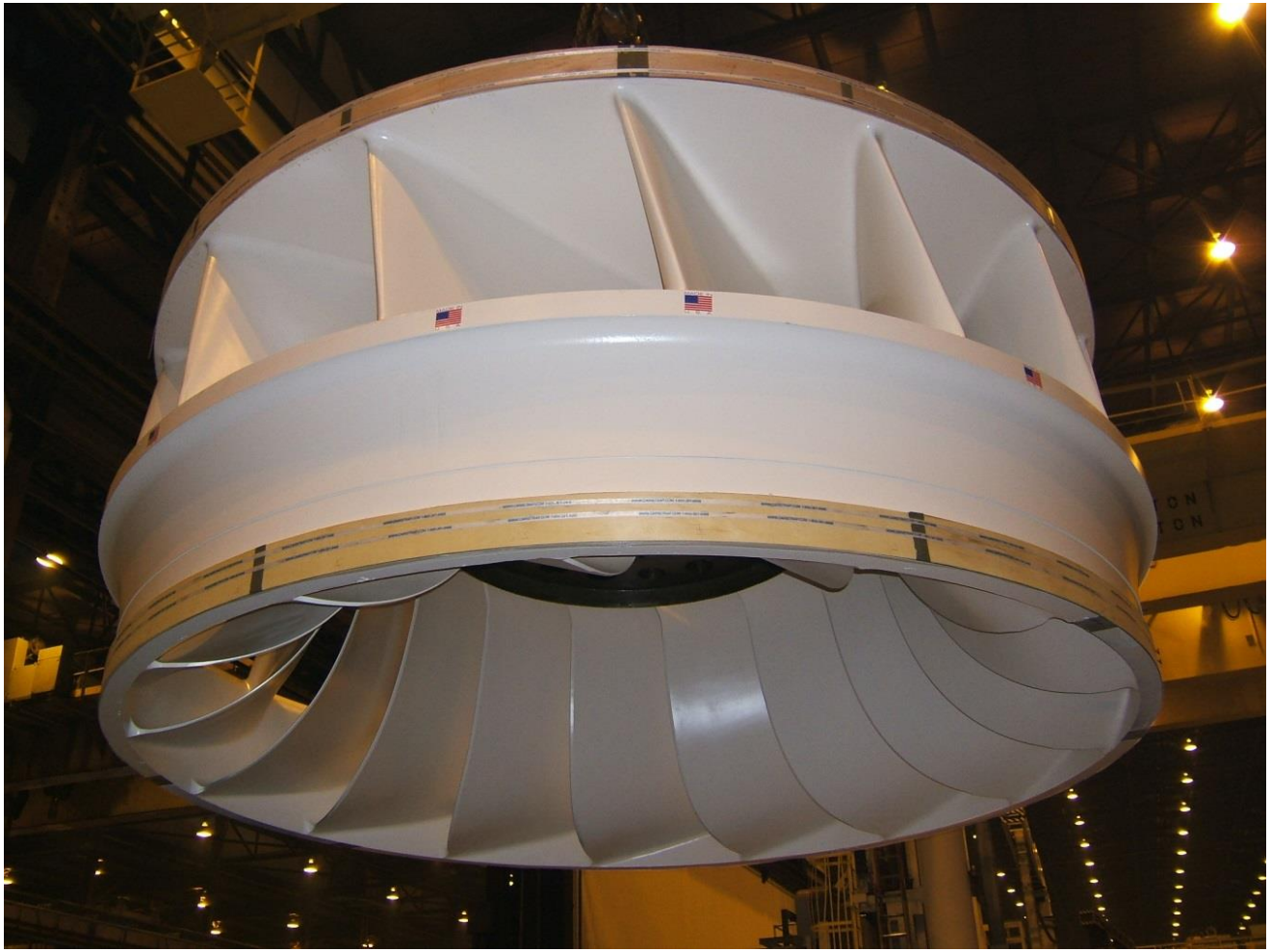
Voith Hydro Services AMB Sales Manager West

Water Path Cross Section



Fabricated Francis Runner

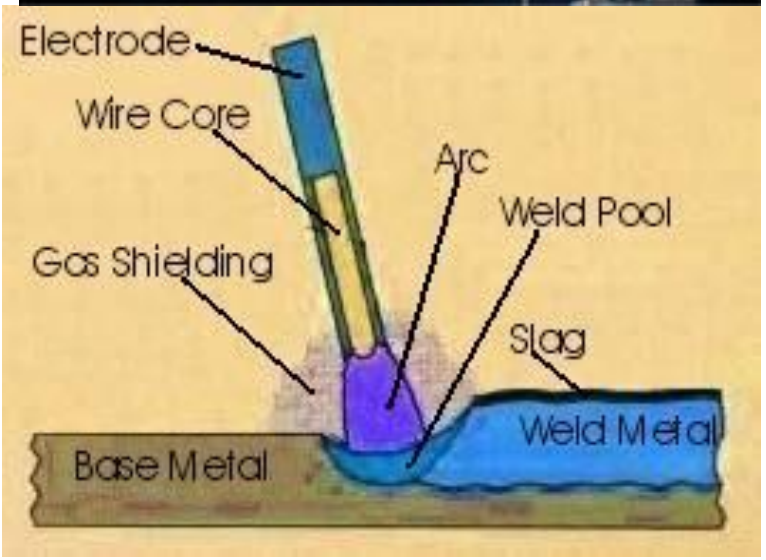


Typical Welding Processes in Hydro

- SMAW – Shielded Metal Arc Welding (Stick)
- GTAW – Gas Tungsten Arc Welding (TIG)
- GMAW – Gas Metal Arc Welding (MIG)
- FCAW – Flux Core Arc Welding (Fluxcor or dual shield)

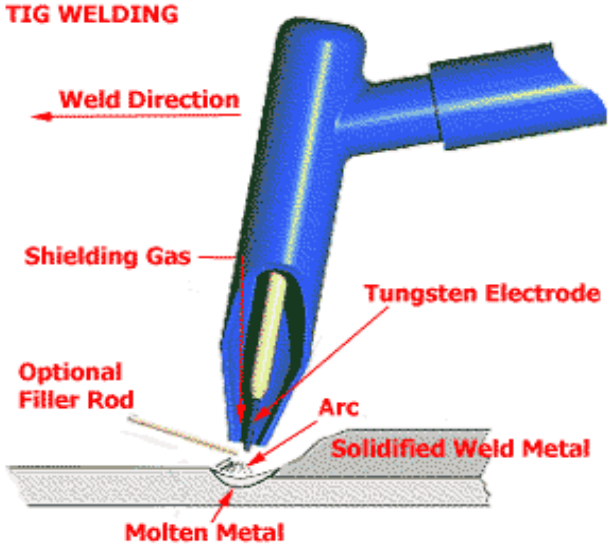
Shielded Metal Arc Welding (SMAW)

- Portable
- Requires little setup time
- Welds most ferrous materials
- Good for out of position
- Low deposition rates
- Very flexible use
- Low cost



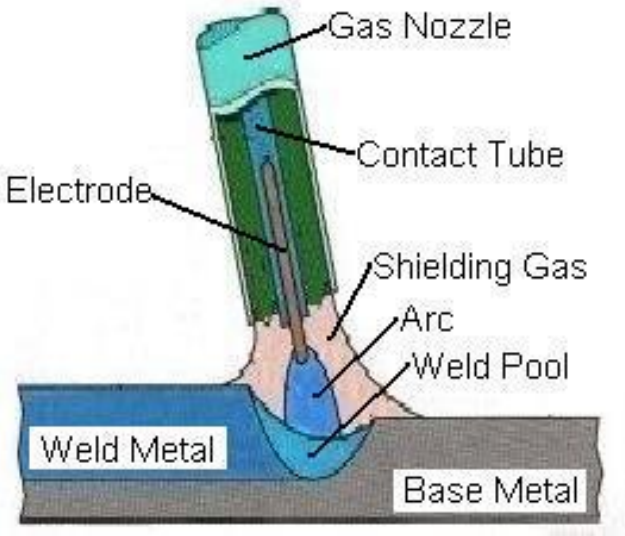
Gas Tungsten Arc Welding (GTAW)

- Utilizes a non-consumable tungsten electrode
- Inert gas provides shielding
- Good for small repairs and thin materials
- Welds the most materials of any process
- Works great out of position
- Extremely low deposition rates
- Use with or without filler material



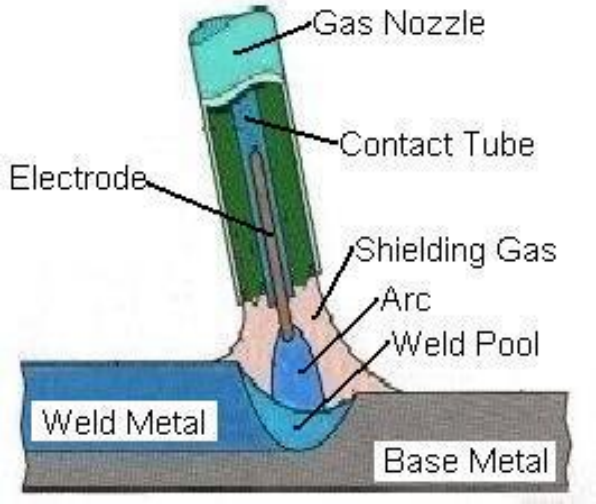
Gas Metal Arc Welding (GMAW)

- Utilizes a consumable solid wire electrode
- Gas shielded
- Higher productivity than other manual processes
- Utilizes a constant voltage power supply with wire feed speed and voltage controls
- Increased amount of moving parts and consumables
- Increased cost



Flux Cored Arc Welding (FCAW)

- Utilizes a consumable electrode with internal flux
- Same welding equipment is used for GMAW
- Used with or without gas shielding
- Good for out of position
- Medium to high deposition rates
- Flux adds several benefits to welding
- Good process for semi or full automation



What is a welding process?

- In the hierarchy of welding the ‘types’ used in Hydro the welding processes mentioned are all Fusion Welds
- Specifically “arc” welding. High Amperage Low Voltage.
- Electric Arc between electric and base metal. Temperatures exceeding 5000 Centigrade, melts base metal and filler, material coalesces, fuses, cools, solidifies = weld
- SMAW, GTAW, GMAW and FCAW all fusion, all arc
- Regardless of type they all need a recipe, the parameters
- Used in original manufacture, rehab and repair

Focus on repair welding processes

- Most of us, whether contractors or owner operators, are going to be involved with repairs at some point in time
- Understanding the welding process choices
- Electric Arc between electrode and base metal. Temperatures exceeding 5000 Centigrade, melts base metal and filler, material coalesces, fuses, cools, solidifies = weld
- SMAW, GTAW, GMAW and FCAW all fusion, all arc
- Regardless of type they all need a recipe, the parameters
- Used in original manufacture, rehab and repair

Focus on repair welding processes

- SMAW is easy to set up, mobile, flexible, usable on most Hydro materials
- Best suited to small jobs
- Requires more skill in arc length control than is generally understood, especially when using Low Hydrogen electrodes
- Poor control can lead to porosity and hydrogen embrittlement

Focus on repair welding processes

- GTAW is easy to set up, mobile, flexible, usable on most Hydro materials,
- Best suited to very small low deposition jobs or where surface conditioning is required or thin materials
- Requires more skill in arc length control than is generally understood
- Poor arc angle control can lead to porosity due to loss of gas coverage and atmospheric entrainment

Focus on repair welding processes

- GMAW requires more welder familiarity to set up, relatively mobile, flexible, usable on most Hydro materials
- Best suited to medium size jobs or thin materials where globular or short circuiting mode can be used. Note there are special qualification requirements for Short Circuit mode
- Requires more skill in understanding the transfer mode and tuning of the process parameters
- Requires care to ensure gas coverage is not lost causing porosity. May need draft protection

Focus on repair welding processes

- FCAW same equipment as GMAW, requires more welder familiarity to set up, relatively mobile, flexible, usable on most Hydro materials
- Well suited to most size jobs best in globular transfer mode. Can provide substantial deposition rates depending on material and position
- Welding wire/electrode has a core of flux
- Requires more skill in understanding the transfer mode and tuning of the process parameters
- More tolerant of atmospheric disturbance due weld pool protection by Flux, can be used with or without gas shield

Focus on repair welding processes

- What type of base material are you welding on?
- What is the application? Structural, high pressure?
- Proper preparation is the key element of success
- Surfaces must be clean ‘bright’ metal and dry.
- Full penetration welds needs appropriate joint geometry
- Pre heat may be required; temperature and duration are factors
- If using SMAW be aware that Low Hydrogen electrodes require proper storage and in process handling

Turbine Component Damage

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Cavitation

Turbine Component Damage

Cracks

Turbine Component Damage

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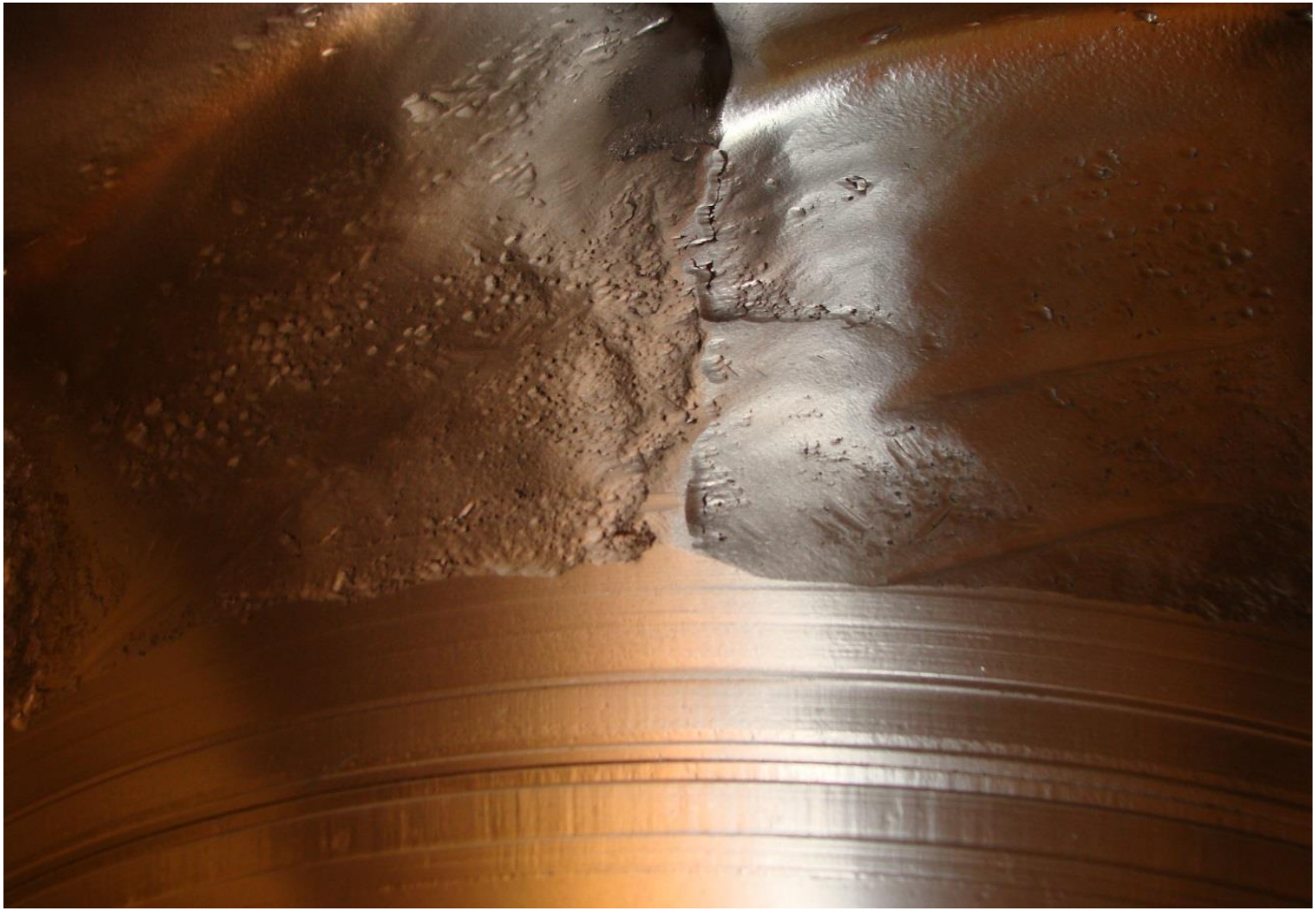
Erosion



Turbine Component Damage

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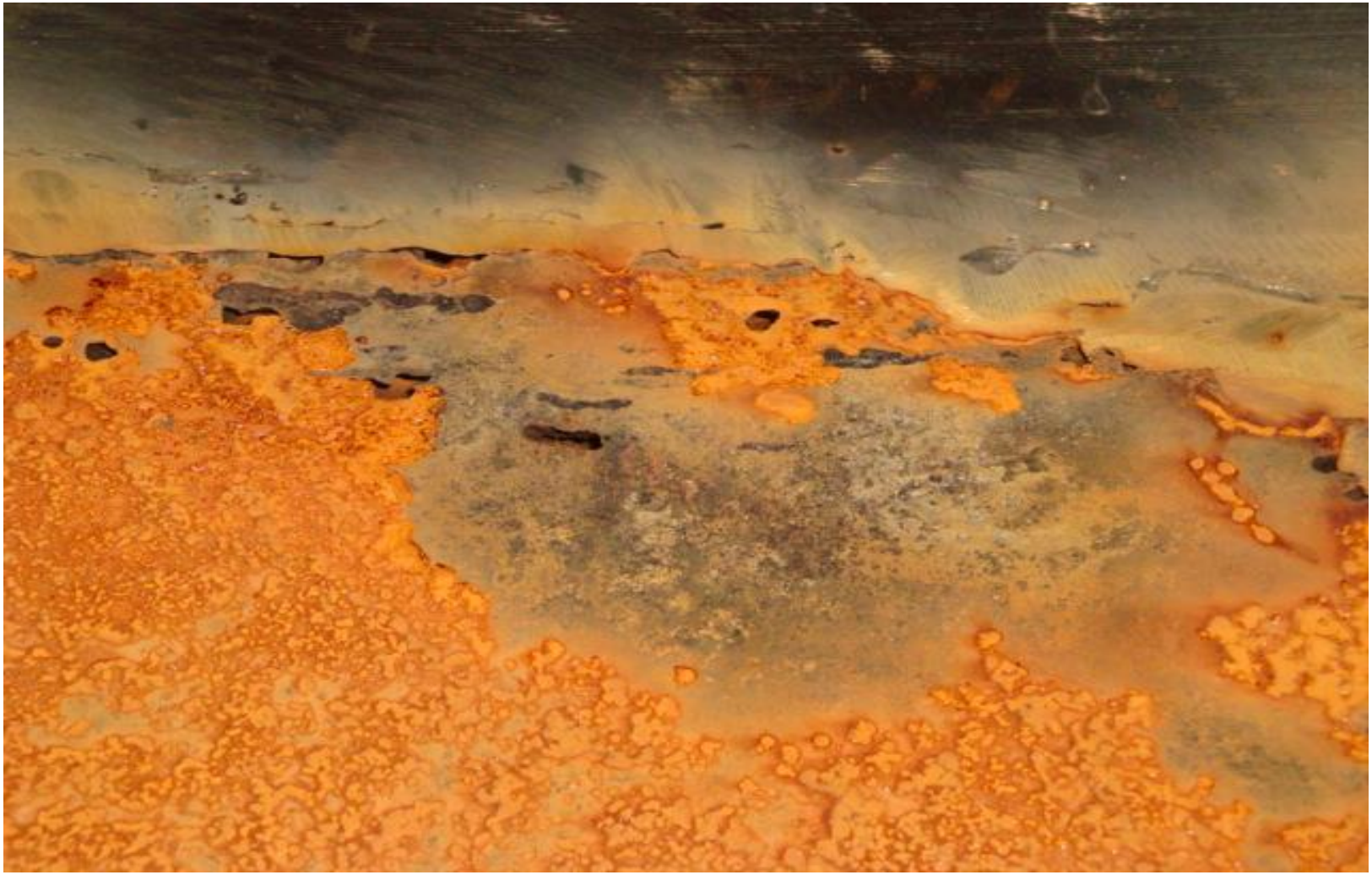
Corrosion



Key Components to Successful Weld Repair

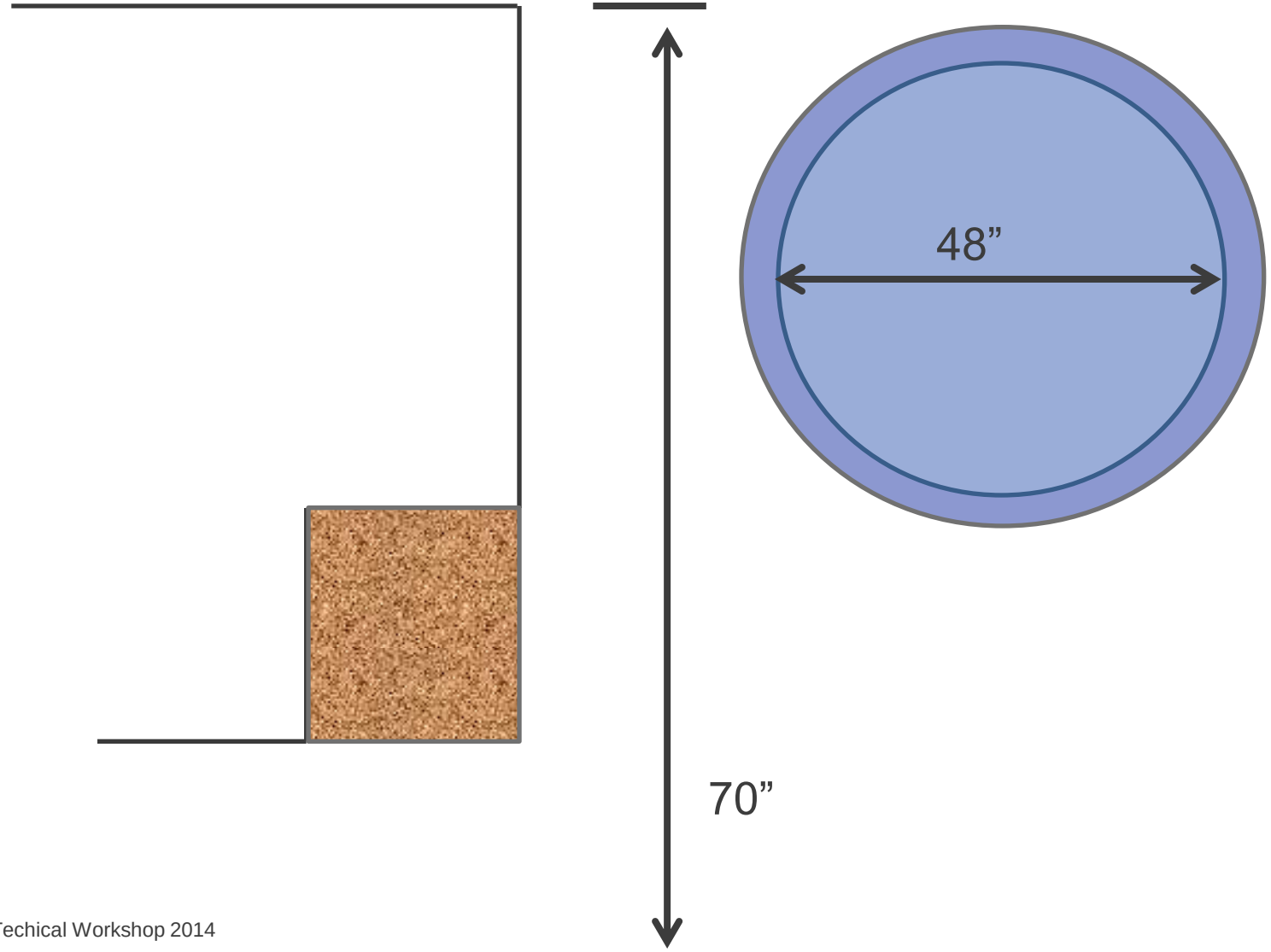
- Success requires planning and knowledge
- Compliance to all Safety Requirements
- Know what material you are welding
- Selection of the appropriate process type
- Welding procedure qualified to applicable welding code
- Experienced, practiced personnel
- Proper weld preparation, supplementary instructions
- Proper Non-Destructive Testing (NDT) procedures
- Welding and NDT Personnel Properly Qualified

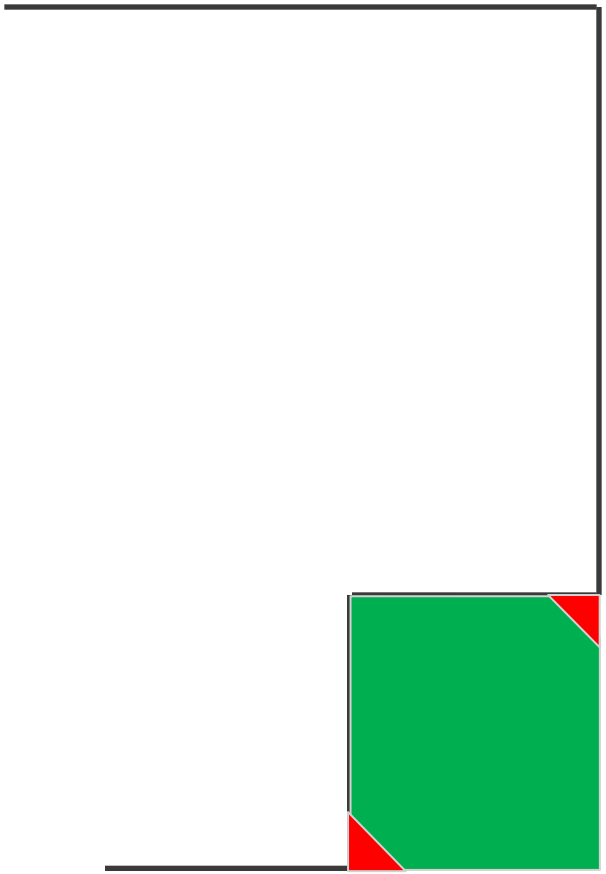
Supplementary Process Instructions

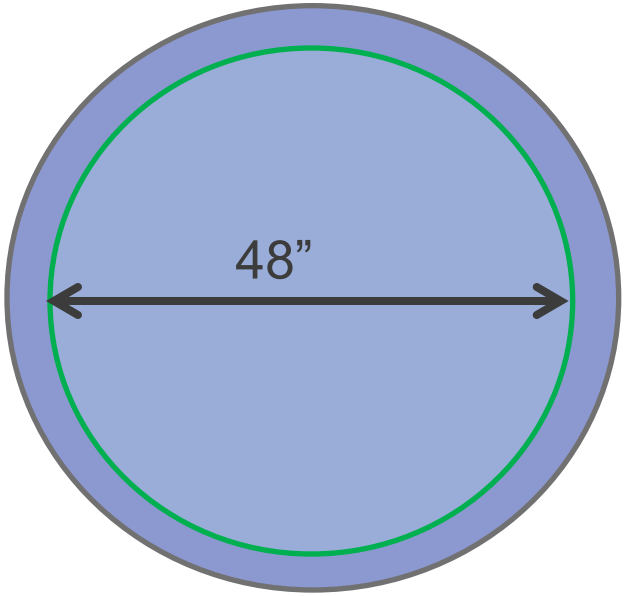
90 Repair cracks; Select blade with the longest crack. Determine if there is any offset in blade (step at the crack/misalignment), if so adjust blade using pancake jacks. Tack weld if necessary. Confirm crack lengths are the same on both suction and pressure sides. Mark the visible end on the longest side, or if both the same on the suction side. Then grind 2 inch long groove beyond the end of the crack at the inboard end. Groove depth should be 50% of the blade thickness.

100 Weld 2 inch groove; start welding at inboard end on surface of existing fillet weld and run weld bead into the 2 inch groove and finish weld out of groove approximately 1 inch beyond groove on the existing fillet toward outboard end.

Key Components to Successful Weld Repair


48”
70”




48”

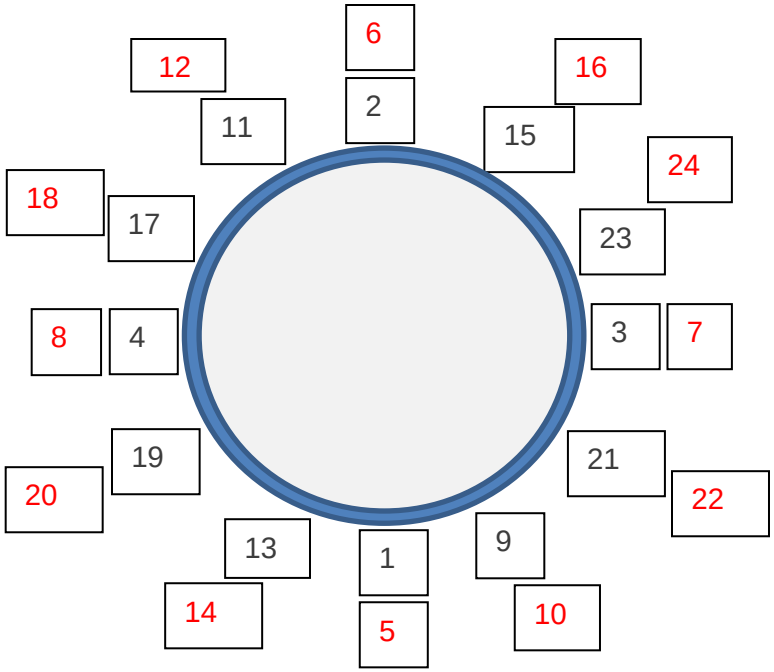
Supplementary Procedures for Process Distortion Control

- Large flange, small ring, small welds
- Customer wanted to minimize flange face machining
- Potential for heating of ring to cause expansion and distortion
- Implementing supplementary process procedures to control heat input and reduce distortion
- Flange chemistry was medium carbon 0.5 -0.6%, potential for cracking of base material
- Requires preheating, large valves, large heat sink, concerns about seat seals

TACK WELD SEQUENCE

BLACK NUMBER ON VALVE BORE/RING ID

RED NUMBERS ON FLANGE/RING FACE

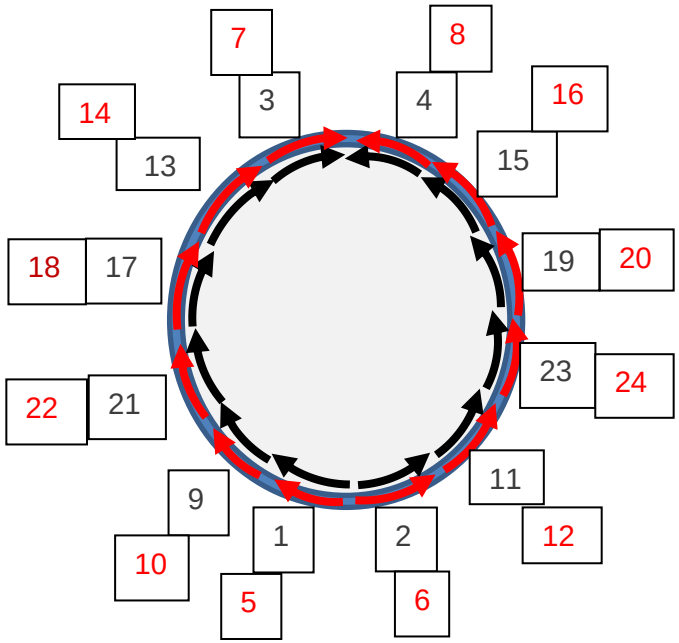


Tack Welds will be spaced approximately 12.5 inches apart

WELD SEQUENCE

BLACK NUMBER ON VALVE BORE/RING ID

RED NUMBERS ON FLANGE/RING FACE



Machine after welding

- Any guesses on TIR after welding?
- TIR from 48-51 inches = 0.005”
- Remainder of the flange face unaffected

Cavitation

- Most common repair is cavitation
- Can be local isolated areas such as runner buckets/blades
- Or large essentially continuous areas such as discharge rings of draft tubes. Can be 1000-2000 pounds of weld
- Preparation of the area
- Carbon Arc Gouging, grinding or machining
  - CAG can leave surface carbon deposits, must grind to bare clean metal
- Depth (minimum) and edge geometry are critical to success
- Can overlay by matching base material or with differing material

CONCLUSIONS

- FCAW probably most commonly used in medium to high deposition applications
- Filler materials are generally spooled in higher weights than maintenance operations can use for casual repairs
- Filler wire / welding electrode storage critical
- Be aware of all safety hazards; fumes (Chromium Hexavalent); intense ultraviolet radiation; electrocution; burns

Conclusions

- Improper processing will shorten equipment life
- Process procedures need to be developed and qualified
- Welders need to be experienced, practiced and qualified
- May need supplementary procedures and instruction
- Most entities possess capability to weld, but lack the theoretical and engineering knowledge to support the processes
- If Weld Processing is not the principal day-to-day business why attempt it?
- Respect the process, if no in house expertise, obtain consultation or contractor expertise

VOITH
Engineered Reliability